Spatially Resolved Two-Dimensional T1-T2 Relaxometry in the Human Brain Using Inversion-Recovery Spin-Echo Measurements and NNLS

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Introduction

Over the last two decades various techniques have been implemented to obtain quantitative spectral information of T1, T2, T2* and M0 values. Bi- or tri-exponential decay fits, inverse Laplace transform and nonnegative least squares (NNLS) are the typical approaches to solve the inverse problem and to obtain the decay-time distribution from multi-echo data. In the human brain, fast-relaxing T2 or T2* components have been successfully correlated with myelin water content. Two-dimensional analysis has also been carried out *in vitro* on frog sciatic nerve [1], *ex-vivo* [2] and *in vivo* [3] for T1-T2 correlations in brain. In this study, T1-T2-correlated spectra of a formalin-fixed post mortem brain were obtained using multiple inversion recovery spin echo (IR-SE) measurements and NNLS.

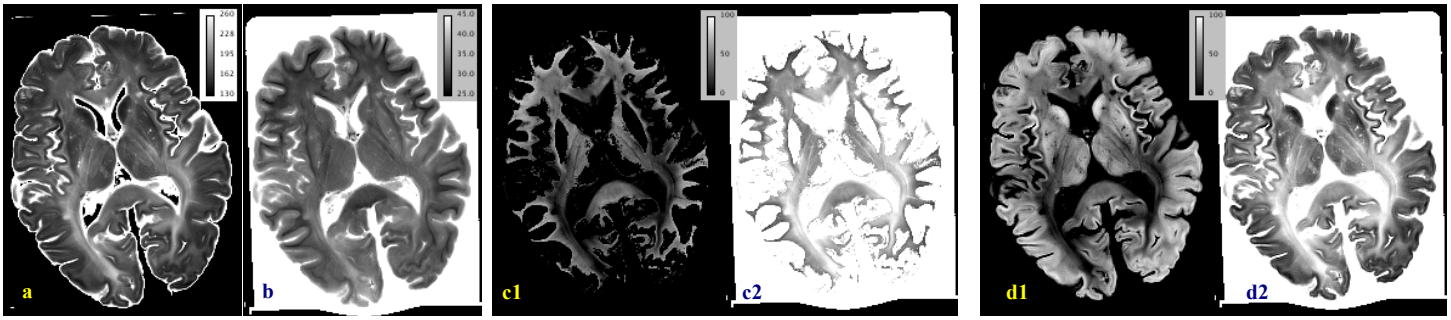

Figure 1: Mean values of (a) T1 and (b) T2 (gray scale in ms). Short and long component fraction maps for (c1, c2) T1</>180ms, T2</>22ms and (d1, d2) T1</>180ms, T2</>36ms, normalized for each pixel (in %).

Materials and Methods

A formalin fixed human brain with no indication of neurological disease was scanned in a 3 Tesla system with an 8-channel phased array coil using multiple IR-SE scans with varying inversion times. 32 echoes were acquired within one read-out train with an echo spacing of 8.7ms. The first echo was acquired at 8.7ms. 16 inversion times were used spanning the range of 22ms to 1600ms quasi-logarithmically. Matrix size/resolution was 256x192/0.75x0.75mm^2 and slice thickness was 2mm.
The data were analyzed with NNLS in a two-dimensional fashion [4-7] with the origin as starting point, to the equation

$$s(TE,TI) = \sum_i \sum_j a_{i,j} \cdot (1 - 2 \cdot k \cdot \exp(-TI / T_{1,i})) \cdot \exp(-TE / T_{2,j}),$$

where k is the inversion efficiency of the 180° RF-pulse. k was kept constant at k=0.90, after careful investigation using a single exponential T1-fit assuring that it does not vary severely within brain tissue (<±2%). The solution was regularized, such that $1.02 \cdot \chi_{\min}^2 \le \chi^2 \le 1.025 \cdot \chi_{\min}^2$, where $\chi_{\min}^2$ belongs to the unregularized solution. Explicit magnetization transfer effects were neglected. For further analysis the outer bins of the solution were ignored because they contain erroneous information due to noise.

Results and Discussion

Figure 1 displays the mean T1 and T2 map, short and long component maps for different borders. Diverse WM and GM structures can be distinguished and characteristic water pools can be identified. Figure 2 shows representative T1-T2 distributions of two single pixels, one located in the right frontal white matter (a), and one in dorsal grey matter (b). Multiple components were found in all voxels. Throughout the whole slice, WM distributions were much wider than in GM. The substructure of the T1 distribution can be better distinguished with the aid of the T2 distribution. Differences between brain regions might be caused to some extent by non-ideal inversion efficiency.

To our knowledge, no study has been published investigating correlated 2D T1-T2-relaxometry in the human brain. Unfortunately, due to the changes in the properties of the tissue caused by fixation and the long conservation time, comparison to the sparse existing quantitative studies is not straightforward. Moore et al. [8] performed an NNLS analysis on T2 data from fixed tissue and used 30 ms as the upper limit for myelin water in fixed brain. Similar values are found in this study.

Conclusion

Correlated T1-T2 spectra were obtained in one brain slice using multiple IR-SE scans and 2D NNLS for data analysis. The results show tissue-characteristic distributions with multiple peaks. Association of the T1 and corresponding T2 compartment is possible, and the T2 information facilitates analysis of the spectral T1 distribution.

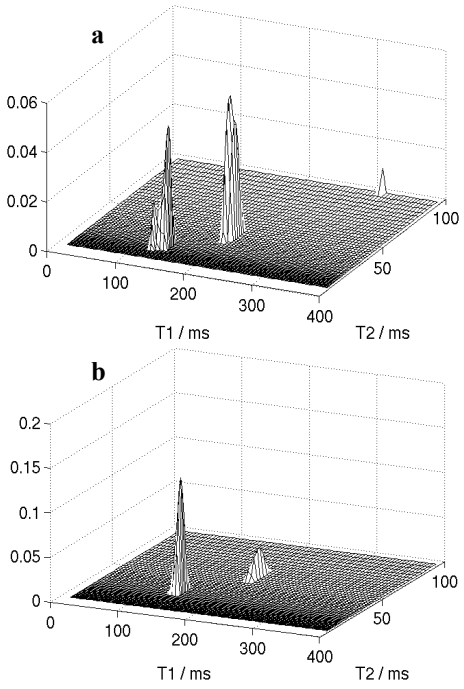

Figure 2: Representative T1-T2 distributions from a single (a) frontal white matter and (b) temporal grey matter pixel. Axes in ms, amplitudes normalized. Peak volumes are 49% short/45% long (WM) and 82% short/16% long (GM).

References

[1]Travis & Does, *MRM* **54** (2005); [2]Dortch, *MRM* **64** (2010); [3]Does & Gore, *MRM* **47** (2002); [4]Lawson & Hanson, Prentice Hall, Englewood Cliffs, NJ, 1974; [5]MacKay, *MRM* **31** (1994); [6]English, *MRM* **22** (1991); [7]Saab, *MRM* **46** (2001); [8]Moore, *Neurology* **55** (2000).